

WHAT IS CLAIMED IS:

1. A data classification method of classifying a group of data into a plurality of sets in accordance with data values, comprising:

dividing said group of data into a first number of sets having no common elements; and

calculating a first total degree of randomness which is a sum of degrees of randomness of said data values in said respective sets of said first number of sets,

wherein data division to said first number of sets and calculation of said first total degree of randomness are repeated while a form of data division to said first number of sets is changed, and said group of data is classified into data belonging to the respective classification sets of said first number of classification sets in which said first total degree of randomness is minimized.

2. The method according to claim 1, wherein data division to said first number of sets is performed for data to be classified in numerical order of data values.

3. The method according to claim 1, wherein said calculating the sum of degrees of randomness in the respective sets of said first number of sets comprises: estimating a probability distribution of data

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values in each of said sets on the basis of said data values of said data belonging to each of said sets;

obtaining an entropy of each of said estimated probability distributions of data values; and

5 weighting said entropy of each of said probability distributions in accordance with the number of data belonging to a corresponding one of said sets.

4. The method according to claim 3, wherein said
10 first probability distribution is a normal distribution.

5. The method according to claim 1, further comprising:

dividing data belonging to a specific
15 classification set in said first number of classification sets into a second number of sets having no common elements; and

calculating a second total degree of randomness which is a sum of degrees of randomness of data values in
20 the respective sets of said second number of sets,

wherein data division to said second number of sets and calculation of said second total degree of randomness are repeated while a form of data division to said second number of sets is changed, and said data belonging to
25 said specific classification set are further classified into data belonging to the respective classification sets of said second number of classification sets in which said second total degree of randomness is minimized.

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6. The method according to claim 5, wherein data division to said second number of sets is performed for data to be classified in numerical order of data values.

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7. The method according to claim 5, wherein said calculating the sum of degrees of randomness in the respective sets of said second number of sets comprises:

estimating a probability distribution of data values in each of the sets on the basis of said data values of said data belonging to each of said sets;

obtaining an entropy of each of the estimated probability distributions of data values; and

weighting said entropy of each of said probability distributions in accordance with the number of data belonging to a corresponding one of said sets.

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8. The method according to claim 7, wherein said first probability distribution is a normal distribution.

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9. A data classification apparatus for classifying a group of data into a plurality of sets in accordance with data values, comprising:

a first data dividing unit which divides said group of data into a first number of sets having no common elements; and

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a first degree-of-randomness calculation unit which calculates degrees of randomness of data values in the

respective sets divided by said first data dividing unit,
and calculates a sum of the degrees of randomness; and

5 a first classification unit which classifies said
group of data into said data belonging to the respective
classification sets of said first number of
classification sets in which said sum of degrees of
randomness calculated by said first degree-of-randomness
calculation unit is minimum out of forms of data division
by said first data dividing unit.

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10. The apparatus according to claim 9, further
comprising:

15 a second data dividing unit which divides data
belonging to a specific classification set in the first
number of classification sets into a second number of
sets having no common elements; and

20 a second degree-of-randomness calculation unit
which calculates degrees of randomness of data values in
the respective sets divided by said second data dividing
unit and calculates a sum of the degrees of randomness;
and

25 a second classification unit which classifies said
data of said specific classification set into said data
belonging to the respective classification sets of said
second number of classification sets in which said sum of
degrees of randomness calculated by said second
degree-of-randomness calculation unit is minimum out of
forms of data division by said second data dividing unit.

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11. A signal processing method of processing a measurement signal obtained by measuring an object, comprising:

5 extracting signal levels at a plurality of feature points obtained from said measurement signal; and

setting said extracted signal levels as classification object data and classifying said signal levels at said group of feature points into a plurality of sets by using the data classification method according to claim 1.

12. The method according to claim 11, wherein said feature point is at least one of a local maximum point and a local minimum point of said measurement signal.

13. The method according to claim 11, wherein said feature point is a point of inflection of said measurement signal.

14. A signal processing apparatus for processing a measurement signal obtained by measuring an object, comprising:

a measurement unit which measures said object and acquires a measurement signal;

an extraction unit which extracts signal levels at a plurality of feature points obtained from said measurement signal; and

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the data classification apparatus according to claim 9, which sets said extracted signal levels as classification object data.

5 15. A position detection method of detecting a position of a mark formed on an object, comprising:

acquiring an image pick-up signal by picking up an image of said mark;

10 processing said image pick-up signal as a measurement signal by said signal processing method according to claim 11; and

calculating said position of said mark on the basis of a signal processing result obtained in said signal processing.

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16. The method according to claim 15, wherein

in data classification in said signal processing, the number of data which should belong to each classification set after said data classification is

20 known in advance, and

in said position calculation, the number of data which should belong to each classification set is compared with the number of data in each of said classification sets classified in said signal processing to evaluate validity of the classification in said signal processing, and said position is calculated on the basis of said data belonging to said classification set evaluated to be valid.

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17. A position detection apparatus for detecting a position of a mark formed on an object, comprising:

an image pick-up unit which acquires an image pick-up signal by picking up an image of said mark;

the signal processing apparatus according to claim 14, which performs signal processing for said image pick-up signal as a measurement signal; and

a position calculation unit which calculates said position of said mark on the basis of a signal processing result obtained by said signal processing apparatus.

18. An exposure method of transferring a predetermined pattern onto a divided area on a substrate, comprising:

detecting a position of a position detection mark formed on said substrate by the position detection method according to claim 15, obtaining a predetermined number of parameters associated with a position of said divided area, and calculating arrangement information of said divided area on said substrate; and

transferring said pattern onto said divided area while performing position control on said substrate on the basis of said arrangement information of said divided area obtained in said arrangement calculation.

19. An exposure apparatus for transferring a predetermined pattern onto a divided area on a substrate,

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comprising:

a substrate stage on which said substrate is mounted; and

the position detection apparatus according to claim 5 17, which detects a position of said mark on said substrate.

20. A data classification method of classifying a group of data into a plurality of sets in accordance with data values, comprising:

classifying said group of data into a first number of sets in accordance with said data values; and

dividing said group of data again into a second number of sets which is smaller than said first number on the basis of a characteristic of each of said first number of sets divided in data classification into said first number of sets.

21. The method according to claim 20, wherein data classification into said second number of sets comprises:

specifying a first set, of said first number of sets, which meets a predetermined condition;

estimating a first boundary candidate for dividing said group of data excluding data included in said first set by using a predetermined estimation technique;

estimating a second boundary candidate for dividing a data group, of said group of data, which is divided by said first boundary candidate and includes said first set

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by using said predetermined estimation technique; and
dividing said group of data into said second number
of sets on the basis of said second boundary candidate.

5 22. The method according to claim 21, wherein said
predetermined estimation technique comprises:

calculating a degree of randomness of data values
in each set divided by said boundary candidate, and
calculating a sum of said degrees of randomness; and

10 performing said degree-of-randomness calculation
while changing a form of data division with said boundary
candidate, and extracting a boundary candidate with which
said sum of degrees of randomness obtained in said
degree-of-randomness calculation is minimized.

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23. The method according to claim 21, wherein said
predetermined estimation technique comprises:

obtaining a probability distribution in each set of
said data group; and

20 extracting said boundary candidate on the basis of
a point of intersection of said probability distributions
of the respective sets.

24. The method according to claim 21, wherein said
25 predetermined estimation technique comprises:

calculating an inter-class variance as a variance
between sets divided by said boundary candidate; and
performing said intra-class variance calculation

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while changing a form of data division with said boundary candidate, and extracting a boundary candidate with which the inter-class variance obtained in said inter-class variance calculation is maximized.

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25. The method according to claim 21, wherein said predetermined condition is a condition that data exhibiting a value substantially equal to a predetermined value is extracted from said group of data.

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26. The method according to claim 25, wherein

said group of data is image pick-up data of the respective pixels obtained by picking up different image patterns within a predetermined image pick-up field; and

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said predetermined value is image pick-up data of a pixel existing in an area corresponding to an image pick-up area for a predetermined image pattern.

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27. The method according to claim 20, wherein said dividing data into said second number of sets comprises:

extracting a predetermined number of sets from the first number of sets on the basis of the number of data included in the respective sets of said first number of sets;

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calculating an average data value by averaging data values respectively representing sets of said predetermined number of sets; and

dividing said group of data into said second number

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of sets on the basis of said average data value.

28. The method according to claim 27, wherein in said average data value calculation, a weighted average of said data values is calculated by using a weight corresponding to at least one of the number of data of the respective sets of said predetermined number of sets and a probability distribution of said predetermined number of sets.

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28. The method according to claim 20, wherein said first number is not less than three, and said second number is two.

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29. The method according to claim 20, wherein said group of data is luminance data of the respective pixels obtained by picking up different image patterns within a predetermined image pick-up field.

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30. A data classification apparatus for classifying a group of data into a plurality of sets in accordance with data values, comprising:

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a first data dividing unit which divides said group of data into a first number of sets on the basis of said data values; and

a second data dividing unit which divides said group of data into a second number of sets smaller than said first number again on the basis of a characteristic

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of each of said first number of sets.

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31. The method according to claim 30, wherein said
first number is not less than three, and said second
5 number is two.

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32. An image processing method of processing image
data obtained by picking up an image in a predetermined
image pick-up field, comprising:

10 setting luminance data, as a group of data, which
is obtained by picking up an image pattern of an object
and an image pattern of a background which exist in said
predetermined image pick-up field; and

15 identifying a boundary between said object and said
background by classifying said luminance data by using
the data classification method according to claim 29.

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33. The method according to claim 32, wherein said
object includes a substrate onto which a predetermined
20 pattern is transferred.

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34. An image processing apparatus for processing
image data obtained by picking up an image in a
predetermined image pick-up field, wherein

25 luminance data, which is obtained by picking up an
image pattern of an object and an image pattern of a
background which exist in said predetermined image pick-
up field is set as a group of data, and

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a boundary between said object and said background is identified by classifying said luminance data by using the data classification apparatus according to claim 30.

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35.

An exposure method of transferring a predetermined pattern onto a substrate, comprising:

specifying an outer shape of said substrate by using the image processing method according to claim 33;

controlling a rotational position of said substrate on the basis of said specified outer shape of said substrate;

detecting a mark formed on said substrate after said rotational position is controlled; and

transferring said predetermined pattern onto said substrate while positioning said substrate on the basis of a mark detection result obtained in said mark detection.

36.

An exposure apparatus for transferring a predetermined pattern onto a substrate, comprising:

an outer shape specifying unit including the image processing apparatus according to claim 34, which specifies an outer shape of said substrate;

a rotational position control unit which controls a rotational position of said substrate on the basis of said outer shape of said substrate which is specified by said image processing apparatus;

a mark detection unit which detects a mark formed

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on said substrate whose rotational position is controlled by said rotational position control unit; and

a positioning unit which positions said substrate on the basis of a mark detection result obtained by said mark position detection unit,

wherein said predetermined pattern is transferred onto said substrate while said substrate is positioned by said positioning unit.

37. A data classification method of classifying a group of data into a plurality of sets in accordance with data values, comprising:

estimating a first number of boundary candidates for dividing said group of data into a second number of sets on the basis of said data values; and

extracting a third number of boundary candidates which is smaller than said first number and is used to divide said group of data into a fourth number of sets smaller than said second number, under a predetermined extraction condition, on the basis of said first number of boundary candidates.

38. The method according to claim 37, wherein said predetermined extraction condition includes a condition that said third number of boundary candidates are extracted on the basis of a magnitude of a data value indicated by each of said first number of boundary candidates.

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39. The method according to claim 38, wherein said
predetermined extraction condition includes a condition
that a boundary candidate with which said data value is
5 maximized is extracted.

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40. The method according to claim 37, wherein
said group of data are arranged at positions in a
predetermined direction, and
10 said predetermined extraction condition includes a
condition that said fourth number of boundary candidates
are extracted on the basis of the respective positions of
said first number of boundary candidates.

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41. The method according to claim 37, wherein
said group of data are differential data obtained
by differentiating image pick-up data of the respective
pixels obtained by picking up different image patterns in
a predetermined image pick-up field in accordance with
15 positions of said pixels,

said data value is a differential value of said
image pick-up data, and

said boundary candidate is a position of said pixel.

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25 42. The method according to claim 37, wherein said
first number is not less than two, and said third number
is one.

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43. The method according to claim 37, wherein said group of data are luminance data of the respective pixels obtained by picking up different image patterns in a predetermined image pick-up field.

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44. A data classification apparatus for classifying a group of data into a plurality of sets in accordance with data values, comprising:

10 a first data dividing unit which estimates a first number of boundary candidates for dividing said group of data into a second number of sets on the basis of said data values; and

15 a second data dividing unit which extracts a third number of boundary candidates which is smaller than said first number and is used to divide said group of data into a fourth number of sets smaller than said second number, under a predetermined extraction condition, on the basis of said first number of boundary candidates.

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45. The apparatus according to claim 44, wherein

25 said group of data are differential data obtained by differentiating image pick-up data of the respective pixels obtained by picking up different image patterns in a predetermined image pick-up field in accordance with positions of said pixels,

said data value is a differential value of said image pick-up data, and

said boundary candidate is a position of said pixel.

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46. The apparatus according to claim 44, wherein said first number is not less than two, and said third number is one.

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47. An image processing method of processing image data obtained by picking up an image in a predetermined image pick-up field, comprising:

10 setting luminance data, as a group of data, which is obtained by picking up an image pattern of an object and an image pattern of a background which exist in the predetermined image pick-up field; and

15 identifying a boundary between said object and said background by classifying said luminance data by using the data classification method according to claim 37.

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48. An image processing apparatus for processing image data obtained by picking up an image in a predetermined image pick-up field, wherein

20 luminance data which is obtained by picking up an image pattern of an object and an image pattern of a background which exist in said predetermined image pick-up field is set as a group of data, and

25 a boundary between said object and said background is identified by classifying said luminance data by using the data classification apparatus according to claim 44.

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49. An exposure method of transferring a

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09758289-062101
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predetermined pattern onto a substrate, comprising:

specifying an outer shape of said substrate by using the image processing method according to claim 47;

controlling a rotational position of said substrate
5 on the basis of said specified outer shape of said substrate;

detecting a mark formed on said substrate after said rotational position is controlled; and

transferring said predetermined pattern onto said
10 substrate while positioning said substrate on the basis of a mark detection result obtained in said mark detection.

51.

50. An exposure apparatus for transferring a
15 predetermined pattern onto a substrate, comprising:

an outer shape specifying unit including the image processing apparatus according to claim 48, which specifies an outer shape of said substrate;

a rotational position control unit which controls a
20 rotational position of said substrate on the basis of said outer shape of said substrate which is specified by said image processing apparatus;

a mark detection unit which detects a mark formed on said substrate whose rotational position is controlled
25 by said rotational position control unit; and

a positioning unit which positions said substrate on the basis of a mark detection result obtained by said mark position detection unit,

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wherein said predetermined pattern is transferred onto said substrate while said substrate is positioned by said positioning unit.

5 51. A recording medium on which a position detection control program executed by a position detection apparatus for detecting a position of a mark formed on an object is recorded, wherein

10 said position detection control program comprises:
allowing an image of said mark to be picked up and allowing an image pick-up signal to be acquired;

a signal processing control program using said image pick-up signal as a measurement signal, comprising
15 allowing signal levels at a plurality of feature points obtained from said measurement signal to be extracted; and

said data classification control program using said extracted signal levels as a group of classification object data, comprising

20 allowing said group of data to be divided into a first number of sets having no common elements;

allowing a first total degree of randomness which is a sum of degrees of randomness of data values in the respective sets of said first number of sets to be
25 calculated; and

allowing said group of data to be divided into data belonging to the respective classification sets of said first number of classification sets in which said first

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total degree of randomness is minimized, by repeating data division to said first number and calculation of said first total degree of randomness while changing a mode of data division to said first number of sets; and

5 allowing a position of said mark to be calculated on the basis of a processing result on said image pick-up signal.

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10 52. The medium according to claim 51, wherein in said data classifying, the number of data which should belong to each classification set after said data classification is known in advance, and

15 the number of data which should belong to each classification set is compared with the number of data in each of said classified classification sets to evaluate validity of said data classifying, and said position is calculated on the basis of data belonging to said classification set evaluated to be valid.

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20 53. A recording medium on which an image processing control program executed by an image processing apparatus for processing image data obtained by picking up an image in a predetermined image pick-up field is recorded, wherein

25 said image processing control program comprises:
allowing luminance data, which is obtained by picking up an image pattern of an object and an image pattern of a background which exist in said predetermined

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image pick-up field, to be set as a group of data;

a data classification control program which allows said luminance data to be classified, comprising:

allowing said group of data to be divided into a
5 first number of sets on the basis of said data values;
and

allowing said group of data to be divided into a
second number of sets smaller than said first number
again on the basis of features of the respective first
10 number of sets; and

allowing a boundary between said object and said
background to be identified.

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54. A recording medium on which an image processing
15 control program executed by an image processing apparatus
for processing image data obtained by picking up an image
in a predetermined image pick-up field is recorded,
wherein

said image processing control program comprises:
20 allowing luminance data which is obtained by
picking up an image pattern of an object and an image
pattern of a background which exist in said predetermined
image pick-up field to be set as a group of data;

a data classification control program which allows
25 said luminance data to be classified, comprising

allowing a first number of boundary candidates for
dividing said group of data into a second number of sets
to be estimated on the basis of said data values;

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allowing a third number of boundary candidates which is smaller than said first number and is used to divide said group of data into a fourth number of sets smaller than said second number, under a predetermined extraction condition, to be extracted on the basis of said first number of boundary candidates; and

allowing a boundary between said object and said background to be identified.

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10 55. A device manufacturing method including a lithography process, wherein exposure is performed by using the exposure method according to claim 18 in said lithography process.

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15 56. A device manufacturing method including a lithography process, wherein exposure is performed by using the exposure method according to claim 35 in said lithography process.

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20 57. A device manufacturing method including a lithography process, wherein exposure is performed by using the exposure method according to claim 49 in said lithography process.

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